(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 232 734 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
21.08.2002 Bulletin 2002/34

(51) Int Cl.[7]: **A61F 9/013**

(21) Application number: **01204167.9**

(22) Date of filing: **29.10.2001**

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE TR
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: **14.02.2001 US 783665**

(71) Applicant: **20/10 Perfect Vision Optische Geraete GmbH**
69123 Heidelberg (DE)

(72) Inventor: **Bille, Josef**
69118 Heidelberg (DE)

(74) Representative: **Shortt, Peter Bernard et al**
TOMKINS & CO.,
5 Dartmouth Road
Dublin 6 (IE)

(54) Apparatus and device for separating lamellae

(57) An apparatus (10) for separating lamellae (50, 50a, 50b, 50c) in the stroma (34) of an eye (26) includes means (12, 14, 16, 20) for finding a focal depth at an interface layer between lamellae (50, 50a, 50b, 50c) in the stroma (34).

Means are provided (12, 18, 20) for sequentially focusing a laser beam (22) to a plurality of focal points (73) in the stroma (34) to photodisrupt stromal tissue, separate the lamellae (50, 50a, 50b, 50c) and create a photodisruptive response thereto. The photodisruptive response is indicative of a diameter of a gas bubble (60, 62) created in the stroma (34) during photodisruption of the stromal tissue.

The apparatus includes further means (14) for alternating from a first energy level to a second energy level when the photodisruptive response is less than a reference value, and from the second energy level to said first energy level when the photodisruptive response is greater than the reference value. Maintenance of a proper focal depth can be periodically verified by maintaining a birefringent reference using an ellipsometer (14). Once the lamellae (50, 50a, 50b, 50c) are separated, a flap of corneal tissue is be created that can be lifted to expose underlying stromal tissue for further surgical photodisruption.

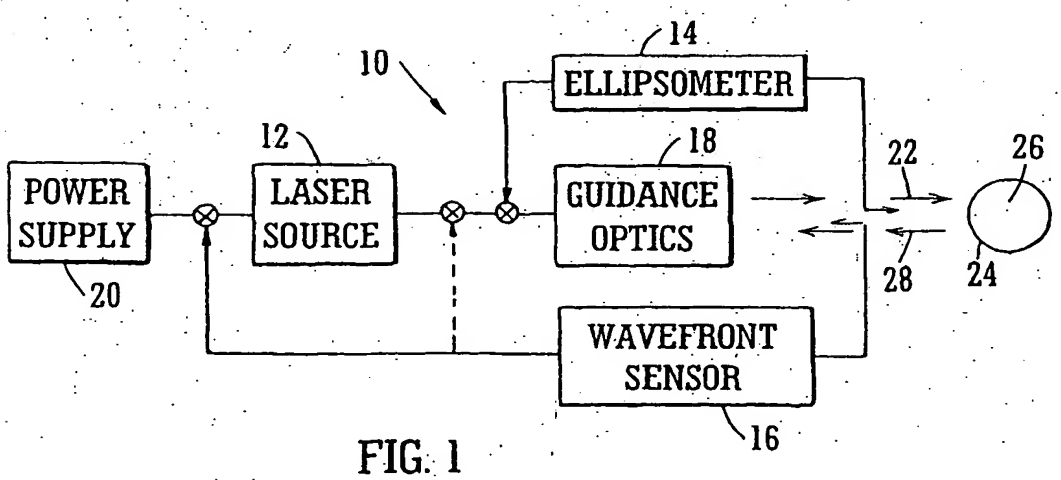

FIG. 1

EP 1 232 734 A1

Description

FIELD OF THE INVENTION

[0001] The present invention pertains generally to apparatus and a device for carrying out ophthalmic laser surgery procedures. More particularly, the present invention pertains to apparatus for separating lamellae in the stroma of the eye. The apparatus is used to carry out laser surgical procedures which are performed to reshape or restructure the cornea of an eye by using photodisruption techniques to remove stromal tissue. The apparatus of the present invention is particularly, but not exclusively, used to create a flap in the cornea of an eye that can be moved or lifted to expose stromal tissue for photodisruption.

BACKGROUND OF THE INVENTION

[0002] Within the past number of years, the so-called LASIK procedure has been used successfully to correct vision difficulties for a significantly large number of patients. In overview, a LASIK procedure is used to reshape or restructure the cornea of an eye in order to change its refractive properties. The object is to thereby minimise optical aberrations and to improve a patient's vision by altering the corneal shape.

[0003] As is well known to those skilled in the art, a LASIK procedure involves the removal of stromal tissue by photodisruption. For a typical LASIK procedure, this photodisruption is accomplished using an "excimer" laser. Excimer lasers, however, are most effective when they are used to superficially photodisrupt tissue. Accordingly, when using an excimer laser for the photodisruption of tissue, it is necessary to somehow expose the target tissue that is to be photodisrupted. In the case of a LASIK procedure, it has been the practice to mechanically access the target tissue. Heretofore, this has involved the creation of a corneal flap which can be moved, or lifted, to expose the target tissue. The "excimer" laser is then used to photodisrupt the exposed stromal tissue. After the photodisruption of tissue is accomplished, as desired the flap can be repositioned over the stroma. A major benefit of this so-called "Flap and Zap" procedure is that trauma to the epithelial layer at the anterior surface of the cornea is minimised. Trauma to the stroma under the epithelial layer, however, may still be significant.

[0004] A general knowledge of the anatomy of the cornea of an eye is helpful for appreciating the problems that must be confronted whenever a corneal flap is created. More specifically, the cornea comprises various layers of tissue which are structurally distinct. In order, going in a posterior direction from outside the eye toward the inside of the eye, the various layers in a cornea are: an epithelial layer, Bowman's membrane, the stroma, Decimet's membrane, and an endothelial layer. Of these various structures, the stroma is the most extensive and is generally around four hundred microns thick.

[0005] In detail, the stroma of the eye is comprised of around two hundred identifiable and distinguishable layers of lamella. Each of these layers of lamella in the stroma is generally dome-shaped, like the cornea itself, and they each extend across a circular area having a diameter of approximately six millimetres. Unlike the layer that a particular lamella is in, each lamella extends through a shorter distance of only about one tenth to one and one half millimetres. Thus, each layer includes several lamellae. Importantly, each lamella includes many fibrils which, within the lamella, are substantially parallel to each other. The fibrils in one lamella, however, are not generally parallel to the fibrils in other lamellae. This is so between lamellae in the same layer, as well as between lamellae in different layers. Finally, it is to be noted that, in a direction perpendicular to the layer, the individual lamella are only about two microns thick.

[0006] Within the general structure described above, there are at least three important factors concerning the stroma that are of interest insofar as the creation of a corneal flap is concerned. The first of these factors is structural, and it is of interest here because there is a significant anisotropy in the stroma. Specifically, the strength of tissue within a lamella is approximately fifty times the strength that is provided by the adhesive tissue that holds the layers of lamella together. Thus, much less energy is required to separate one layer of lamella from another layer (i.e. peel them apart), than would be required to cut through a lamella. The second factor is somewhat related to the first, and involves the stromal tissue response to photodisruption. Specifically, for a given energy level in a photodisruptive laser beam, the bubble that is created by photodisruption in the stronger lamella tissue will be noticeably smaller than a bubble created between layers of lamellae. The third factor is optical, and it is of interest here because there is a change in the refractive index of the stroma between successive layers of lamellae. This is due to differences in the orientations of fibrils in the respective lamella. When consideration is given to using a laser beam for the purpose of creating a corneal flap in a LASIK procedure, these factors can be significant.

[0007] In light of the above, it is an object of the present invention to provide an apparatus to separate lamella in the stroma of an eye which minimises the heating of the stromal tissue. Another object of the present invention is to provide apparatus and a device which utilises a laser beam to separate lamellae in the stroma of an eye that can be accomplished quickly in order to minimise the time a patient must fixate. Still another object of the present invention is to provide apparatus for separating lamellae in the stroma that avoids excessive trauma to the stromal tissue in the cornea. Yet another object of the present invention is to provide apparatus and a device for separating lamellae in the stroma that is easy to use and is comparatively cost effective in operation.

SUMMARY OF THE PREFERRED EMBODIMENTS

[0008] In accordance with the present invention, an apparatus for separating lamellae in the stroma of an eye which comprises means for finding a focal depth in the stroma, means for sequentially focusing a laser beam to a plurality of focal points in the stroma to photodisrupt stromal tissue at said focal depth to separate the lamellae and create a photodisruptive response thereto, said photodisruptive response being indicative of a diameter of a gas bubble created in the stroma during photodisruption of the stromal tissue, and means for alternating from a first energy level to a second energy level when said photodisruptive response is less than a reference value, and from said second energy level to said first energy level when said photodisruptive response is greater than said reference value.

[0009] Suitably, the finding means comprises a wavefront sensor by means of which the anterior surface of the cornea can be identified.

[0010] The invention also includes a device for separating lamellae using a birefringent reference generated in a photodisruptive material which comprises an optical system for focusing a laser beam to a focal point in the material to create a photodisruptive response thereto, said photodisruptive response being indicative of a diameter of a gas bubble created in the material during photodisruption of the material, a computer means for comparing said photodisruptive response to a reference value, a mechanism for scanning said laser beam to another focal point in the material to perform photodisruption of the material, a means for alternating energy in said laser beam from a first energy level to a second energy level when said photodisruptive response is less than said reference value and from said second energy level to said first energy level when said photodisruptive response is greater than said reference value and a means for detecting the birefringent reference in the material when said first energy level is used, said birefringent reference being indicative of an interface between layers of lamellae.

[0011] Operation of the apparatus of the invention first involves locating a start point in the stroma. Preferably, this start point will be at a distance into the stroma that is approximately one hundred and eighty microns from the anterior surface of the cornea. Once the start point is located, tissue at the start point is photodisrupted to create a bubble. The size of this bubble is then measured and compared with a reference to determine whether the bubble was created within a lamella or between layers of lamellae. If the bubble is created inside a lamella, subsequent bubbles can be created at different points in the stroma until the resultant bubble size indicates that photodisruption is occurring between layers of lamellae. An ellipsometer is then used to detect a birefringent condition in the stroma between these layers of lamellae. Specifically, this birefringent condition will result from a change in the orientation of fibrils in the respective lamella, and will be indicative of the interface between layers of lamellae in the stroma. Further, it happens that from layer to layer of lamellae there will be a birefringent change that is manifested as a change in phase of about one half degree. Recall, the thickness of the lamellae is around two microns. The importance of all this is that the detection of a birefringent change will indicate a change from one layer of lamellae to another. Thus, it can be used to establish and maintain a focal depth in the stroma.

[0012] The photodisruption of tissue along the interface between layers of lamellae in the stroma begins by focusing the laser beam to a focal point at the established focal depth in the stroma. Initially, the laser beam is set to operate at an energy level that is slightly above the threshold for photodisruption of stromal tissue (i.e. above approximately one and one half microjoules for a ten micron diameter spot size). For example, the initial energy level that can be used for the laser beam may be around five microjoules for a ten micron diameter spot. In any event, whenever the laser beam is activated, there will be a photodisruptive response from the tissue that results from the particular energy level that is being used. Importantly, this photodisruptive response will vary according to the energy level of the laser beam, as well as the nature of the tissue that is being photodisrupted.

[0013] As intended for the present invention, the photodisruptive response is measured as the diameter of the gas bubble that is created in the stromal tissue during photodisruption. This photodisruptive response is then compared with the reference value mentioned above to determine whether the initial energy level is sufficient for further operation. For the purposes of the present invention, this reference value is chosen to correspond to a hypothetical gas bubble in the stroma that, as a result of photodisruption, would have a diameter of approximately fifteen microns. Depending on the difference between the photodisruptive response and the reference value, the energy level of the laser beam will either be held constant, or it will be changed. For the present invention, the change in energy level will be between a relatively low energy level (e.g. approximately five microjoules per ten micron diameter spot size) and a relatively high energy level (e.g. approximately fifteen microjoules per ten micron diameter spot size).

[0014] A condition wherein the photodisruptive response is greater than the reference value is indicative that the photodisruption of tissue is occurring in the weaker tissue that is located at the interface between layers of lamella, rather than inside the lamella. Accordingly, further photodisruption is accomplished by maintaining the initial energy level of the laser beam at the relatively lower energy level, and moving its focal point at the focal depth between the layers of lamellae. As this is being done, the ellipsometer can be used periodically to ensure the photodisruption is being done at the same interface between lamellae. This continues as long as

this condition persists. On the other hand, when the photodisruptive response becomes less than the reference value, the indication is that the focal point is no longer located between layers of lamellae. Thus, the energy level needs to be increased to a higher energy level. Also, the focal point needs to be moved until the photodisruptive response is substantially greater than the reference value. At this point, i.e. when the photodisruptive response becomes substantially greater than the reference value, the indication is that the focal point is again between layers of lamella. The energy level of the laser beam is then returned to its former lower value. Also, if desired, the focal depth can be verified by the ellipsometer and adjusted as necessary.

[0015] In the operation of the apparatus of the present invention, the energy level of the laser beam is altered in the above manner to follow the interface between lamella, and it is guided to create a flap from the corneal tissue. Specifically, the focal spot of the laser beam is moved within a boundary that can be generally defined by a first edge and a second edge. More specifically, to create the flap, the first edge should be a substantially straight line between a first point and a second point. The second edge can then be a curved line between the first point and the second point with the curved line having a radius of curvature around the optical axis of the eye of about four and one half millimetres. Further, this curved line should be centred approximately on the optical axis of the eye and extend through an arc of about two hundred and seventy degrees.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] The novel features of this invention, as well as the invention itself, both as to its structure and its operation, will be best understood from the accompanying drawings, taken in conjunction with the accompanying description, in which similar reference characters refer to similar parts, and in which:

Fig. 1 is a schematic diagram, in a closed-loop feedback control format, showing the operative components of the apparatus of the present invention;
Fig. 2 is a logic flow chart of the sequential steps to be accomplished by the apparatus of the present invention;
Fig. 3 is a cross sectional view of the cornea of an eye;
Fig. 4 is a cross sectional view of layers of lamella in the cornea of an eye; and
Fig. 5 is a plan view of the cornea of an eye.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0017] Referring initially to Fig. 1, the operative components of an apparatus according to the present invention are shown schematically in a control loop format and are generally designated 10. As shown, the apparatus 10 includes a laser source 12 which, preferably, is capable of generating a continuous train of ultra-short pulses, with each pulse having a pulse duration of approximately one pico-second. Specifically, it is necessary that each pulse have an energy level that is above the threshold necessary for the photodisruption of stromal tissue (i.e. above approximately one and one half microjoules per ten micron diameter spot size). The apparatus 10 also includes an ellipsometer 14 that is capable of determining the birefringent properties within stromal tissue. For the purposes of the present invention, an ellipsometer of the type disclosed and claimed in U.S. Patent No. 5,822,035, which issued to Bille for an invention entitled "Ellipsometer." Further, Fig. 1 shows that the apparatus 10 includes a wavefront sensor 16, such as a Hartmann-Shack sensor, which is capable of modelling a wavefront. Additionally, the apparatus 10 includes guidance optics 18 that are capable of steering and focusing a laser beam onto predetermined focal points. A power unit 20 is also provided. In combination, these components cooperate with each other to generate a laser beam 22 that is directed to a focal point in the cornea 24 of an eye 26 with a predetermined energy level. Control over this operation, to include the location of the focal point and its energy level, is made possible by using the ellipsometer 14 and the wavefront sensor 16 to monitor reflected light 28 as it is reflected from the cornea 24.

[0018] Referring now to Fig. 2, it will be seen that the operation of the apparatus 10 of the invention begins by establishing a start point (action block 30). In Fig. 3 it will be seen that this start point 32 is established in the stroma 34 of cornea 24. Specifically, the start point 32 is established at a distance 36 that is measured from the anterior surface 38 of the cornea 24 in a direction that is substantially perpendicular to the anterior surface 38. As intended for the apparatus 10, the exact location of the anterior surface 38 can be determined using the wavefront sensor 16, and the distance 36 can then be arbitrarily chosen to be around about one hundred and eighty microns from the anterior surface 38.

[0019] Once a start point 32 has been established in the stroma 34, action block 40 in Fig. 2 indicates that the next step is to photodisrupt tissue at the start point 32 to create a response (i.e. a bubble in the stromal tissue). As indicated by inquiry block 41, this response is then compared with a reference (e.g. 15 μm). If the response is less than the reference, action block 43 indicates the focal point should be moved from the start point 32 through a distance 42 (Fig. 4). This distance 42 will preferably be taken in an anterior direction (indicated by the arrow 44 in Fig. 4) and will, most likely, be less than two microns. It will be appreciated, however, that in some cases this distance 42 may be taken in a posterior direction (indicated by arrow 46 in Fig. 4). In either case, as this movement from the start point 32 is being accomplished, the inquiry block 41 in Fig. 2 indicates that when the response becomes greater than the ref-

erence, reflected light 28 from cornea 24 can be monitored by the ellipsometer 14 to determine a birefringent reference (action block 48). It happens that this birefringent reference can be determined due to a variation in the orientation of tissue in the stroma 34 and will, perhaps, be best understood by reference to Fig. 4.

[0020] In Fig. 4, a portion of the stroma 34 in the cornea 24 of the eye 26 is shown to include a plurality of lamellae 50, of which the lamellae 50a, 50b and 50c are only exemplary. Dimensionally, each of the lamellae 50 in the stroma 34 have a depth 52 that is approximately two microns, and a width 54 that is between approximately one tenth and one and one half millimetres. Thus, the lamellae 50 each have a very thin disk shape. Anatomically, the lamella 50 lie on top of each other in layers that extend across the cornea 24 through a distance 56 that is approximately nine millimetres. As shown in Fig. 4, the individual lamella 50 overlap to some extent and are somewhat randomly arranged. Nevertheless, they create many interface layers that, in general, are substantially parallel to each other and extend all the way across the cornea 24. The interface layer 58 shown in Fig. 4 is only exemplary of the many interface layers in the cornea 24.

[0021] For the purposes of the present invention, an interface layer 58 is important in two aspects. First, the birefringent properties of stromal tissue in the lamella 50 change at the interface layer 58. Recall, from the disclosure above, this change in birefringent properties is due to changes in the orientation of fibrils (not shown) in the lamella 50. Second, the stromal tissue along the interface layer 58 is weaker than stromal tissue inside the lamella 50. Accordingly, the stromal tissue along the interface layer 58 can be effectively photodisrupted at lower energy levels.

[0022] It happens that whenever stromal tissue is photodisrupted, a bubble is formed in the stroma 34. For a given type of tissue, the size of the bubble that is formed will be a function of the energy level in the laser beam 22. In this case, the higher the energy level, the larger the bubble. Further, for a given energy level, the size of the bubble that is formed will be a function of the type of tissue. In this case, with the same energy level, the stronger tissue will yield a smaller bubble and the weaker tissue will yield a larger bubble. With this in mind, consider the bubbles 60 and 62 shown (not to scale) in Fig. 4 that would be formed using a same energy level in the laser beam 22. The larger bubble 60 is shown generally in weaker tissue at the interface layer 58 between the lamella 50a and 50b. On the other hand, the smaller bubble 62 is shown in stronger tissue inside the lamella 50b. Fortunately, as used for the present invention, the respective sizes of the bubbles 60 and 62 will serve as photodisruptive responses that can be measured by the wavefront sensor 16 using relatively well known wavefront techniques. Accordingly, the photodisruptive response of a bubble 60 or bubble 62 can be compared with a reference value, and the energy level of the laser beam 22 can be altered as desired.

[0023] Returning now to Fig. 2, and in light of the above discussion with reference to Fig. 4, it will be appreciated that the combined functions of inquiry block 41 and action block 48 is to find the interface layer 58. This is accomplished whenever the ellipsometer 14 detects a birefringent change. It will happen that this birefringent change will be on the order of plus or minus one half degree. Importantly, finding the interface layer 58 will fix a focal depth for the laser beam 22 that will be a combination of the distances 36 and 42. The apparatus 10 can then begin to photodisrupt stromal tissue (action block 64).

[0024] Action block 64 in Fig. 2 indicates that, at least initially, the apparatus 10 will photodisrupt stromal tissue at a relatively low energy level, e.g. approximately five microjoules per ten micron spot size. As indicated above, if photodisruption begins at this energy level in the interface layer 58 as intended, a relatively large bubble 60 will result. In any event, as indicated by the inquiry block 66, the resultant bubble (photodisruptive response) will be compared with a reference value to determine whether photodisruption at this energy level should continue (inquiry block 66). For the present invention, the reference value will correspond to a hypothetical bubble in stromal tissue (not shown) which would have a diameter of approximately fifteen microns. If the resultant bubble in the stroma 34 has a photodisruptive response that is greater than the reference value, it is indicative of the fact that weaker tissue in the interface layer 58 is being photodisrupted. In this case, the inquiry block 67 may be selectively used to determine whether the birefringent reference has changed. Such a change would be on the order of one half a degree and would indicate that another interface 58' was being photoaltered. If so, action block 68 indicates the birefringent reference can be reset to reestablish on the desired interface 58. In either case, the action block 70 in Fig. 2 indicates that the guidance optics 18 should continue to scan the laser beam 22 through the interface layer 58. As this is being done, the interaction of blocks 64, 66, 67 and 68 in Fig. 2 indicate that a photodisruptive response is continuously being monitored by the wavefront sensor 16.

[0025] Whenever the photodisruptive response falls below the reference value, such as would happen when photodisruption is occurring within a lamella 50 (e.g. bubble 62), action block 72 indicates that the energy level in the laser beam 22 should be increased to a higher energy level. Again, the photodisruptive response is monitored by the wavefront sensor 16. Due to the higher energy level being used, when the laser beam 22 is next focused onto the interface layer 58, the photodisruptive response will most likely be much greater than the reference value. In any event, inquiry block 74 and action block 75 indicates that the laser beam 22 will continue to move and photodisrupt tissue until the photodisruptive response is considerably greater than the reference

value. When this happens, depending on the desires of the operator, the laser beam 22 can continue operation at the relatively lower energy level (action block 64). In either case, blocks 66, 67, 68 and 70 indicate that the photodisruption of stromal tissue will continue until the procedure is ended. Specifically, the procedure is ended when an interface layer 58 having a predetermined dimension has been created.

[0026] It is the purpose of the apparatus of the present invention to create a flap of corneal tissue that can be lifted easily from the eye to expose stromal tissue under the flap to further surgical photodisruption. Accordingly, the apparatus and device of the present invention provide means for the photodisruption of weaker tissue along an interface layer 58 between lamella 50 and to, thereby, use less laser energy. The extent of this photodisruption will be best appreciated with reference to Fig. 5. In Fig. 5, a substantially straight edge 76 is shown between a point 78 and a point 80. Also, a substantially curved edge 82 is shown connecting the point 78 to the point 80. More specifically, the curved edge 82 is generally centred on the optical axis 84 of the eye 26 and has a radius of curvature 86 that defines the edge 82. As shown, the curved edge 82 will extend through approximately two hundred and seventy degrees. Effectively the desired corneal flap will be created between the straight edge 76 and the curved edge 82. Consequently, by photodisrupting tissue between the anterior surface 38 of the cornea 24 and the curved edge 82, a flap of corneal tissue can be lifted from the interface layer 58 to expose stromal tissue under the flap for further photodisruption.

[0027] While the particular apparatus and device as herein shown and disclosed in detail is fully capable of obtaining the objects and providing the advantages herein before stated, it is to be understood that it is merely illustrative of the presently preferred embodiments of the invention and that no limitations are intended to the details of construction or design herein shown other than as described in the appended claims.

Claims

1. An apparatus (10) for separating lamellae (50, 50a, 50b, 50c) in the stroma (34) of an eye (26) which comprises:

   means (12, 14, 16, 20) for finding a focal depth in the stroma (34);
   means (12, 18, 20) for sequentially focusing a laser beam (22) to a plurality of focal points (73) in the stroma (34) to photodisrupt stromal tissue at said focal depth to separate the lamellae (50, 50a, 50b, 50c) and create a photodisruptive response thereto, said photodisruptive response being indicative of a diameter of a gas bubble (60, 62) created in the stroma (34) during photodisruption of the stromal tissue; and
   means (14) for alternating from a first energy level to a second energy level when said photodisruptive response is less than a reference value, and from said second energy level to said first energy level when said photodisruptive response is greater than said reference value.

2. An apparatus (10) as recited in claim 2 wherein said finding means (12, 14, 16, 20) comprises:

   a wavefront sensor (16) for identifying the anterior surface (38) of the eye;
   a measuring means for locating a start point (32) in the stroma (34) at a distance (36) from the anterior surface (38), said distance (36) being approximately one hundred and eighty microns; and
   an ellipsometer (14) for detecting a birefringent change in the stroma (34) within approximately two microns from said start point (32) to establish said focal depth.

3. An apparatus (10) as recited in claim 2 further comprising a wavefront sensor (16) for detecting said photodisruptive response.

4. An apparatus (10) as recited in claim 3 wherein said first energy level is lower than said second energy level.

5. An apparatus (10) as recited in claim 4 wherein a polarisation change due to said birefringence is approximately equal to one half degree, and wherein said reference value is indicative of a gas bubble in the stroma (34) having a diameter of approximately fifteen microns.

6. An apparatus (10) as recited in claim 5 wherein photodisruption of stromal tissue is accomplished within a boundary to create a flap of corneal tissue, said boundary having a first edge (76) and a second edge (82) with said first edge being a substantially straight line (76) between a first point (78) and a second point (80) and said second (82) edge being a curved line (82) between said first point (78) and said second point (80) with said curved line (82) having a radius of curvature (86) around the optical axis (84) of the eye of about four and one half millimetres and said curved line (82) extends through an arc of about two hundred and seventy degrees.

7. A device (10) for separating lamellae (50) using a birefringent reference generated in a photodisruptive material which comprises:

   an optical system (18) for focusing a laser beam

(22) to a focal point in the material to create a photodisruptive response thereto, said photodisruptive response being indicative of a diameter of a gas bubble (60, 62) created in the material during photodisruption of the material;
a computer means for comparing said photodisruptive response to a reference value;
a mechanism (18) for scanning said laser beam (22) to another focal point in the material to perform photodisruption of the material;
a means (16) for alternating energy in said laser beam (22) from a first energy level to a second energy level when said photodisruptive response is less than said reference value and from said second energy level to said first energy level when said photodisruptive response is greater than said reference value; and
a means (14, 16) for detecting the birefringent reference in the material when said first energy level is used, said birefringent reference being indicative of an interface (58, 58') between layers of lamellae (50, 50a, 50b, 50c).

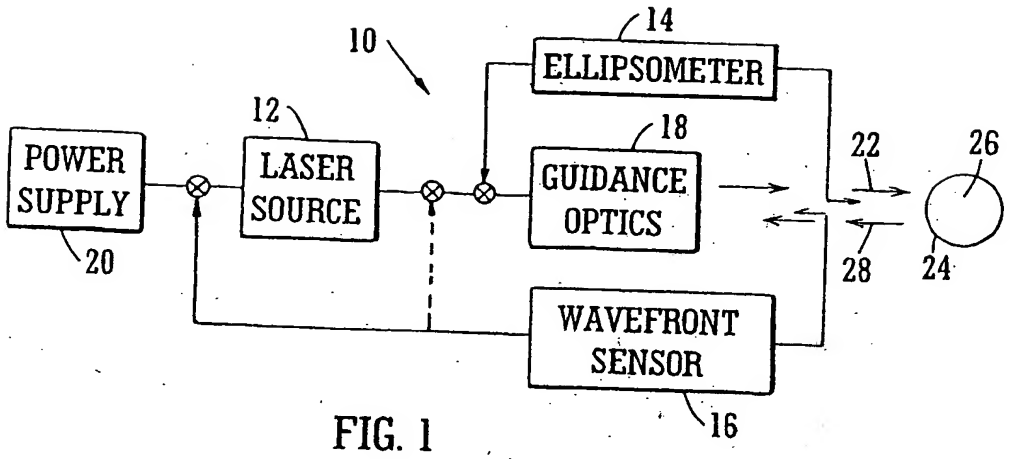

FIG. 1

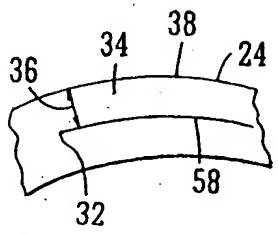

FIG. 3

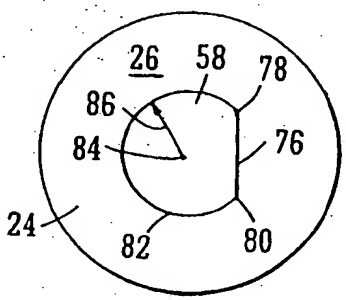

FIG. 5

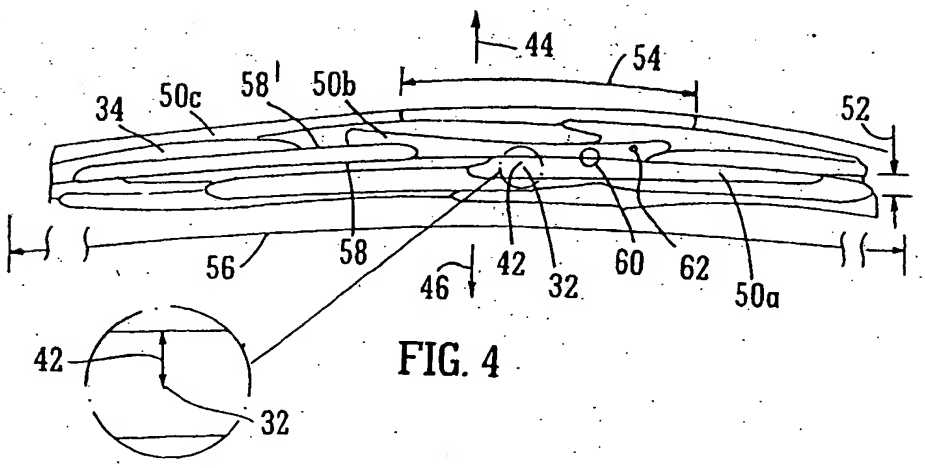

FIG. 4

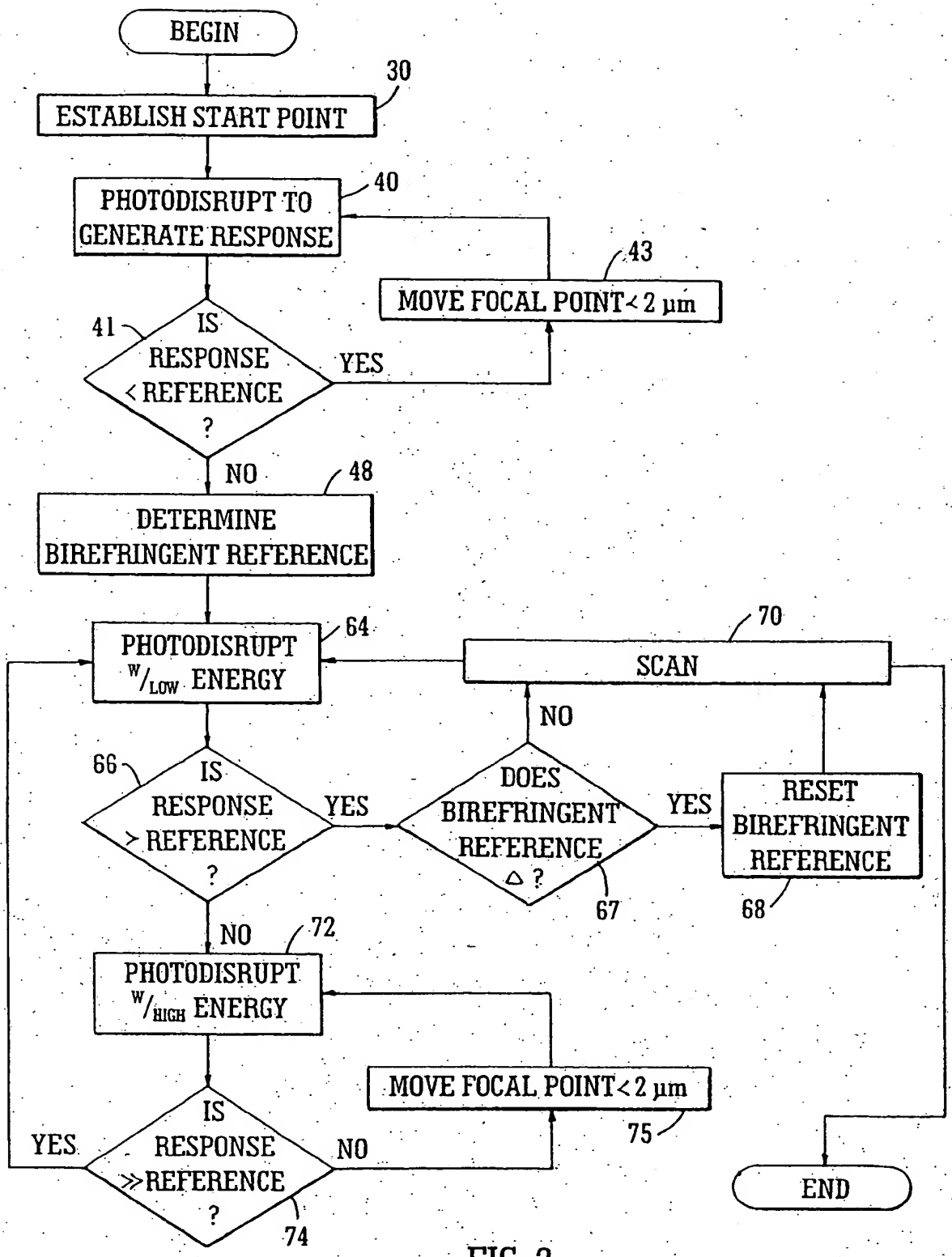
BEGIN
30
ESTABLISH START POINT
40
PHOTODISRUPT TO GENERATE RESPONSE
43
MOVE FOCAL POINT < 2 µm
41
IS RESPONSE < REFERENCE ?
YES
NO
48
DETERMINE BIREFRINGENT REFERENCE
64
PHOTODISRUPT W/LOW ENERGY
70
SCAN
66
IS RESPONSE > REFERENCE ?
YES
DOES BIREFRINGENT REFERENCE Δ ?
YES
NO
67
RESET BIREFRINGENT REFERENCE
68
NO
72
PHOTODISRUPT W/HIGH ENERGY
MOVE FOCAL POINT < 2 µm
75
IS RESPONSE ≫ REFERENCE ?
YES
NO
74
END

FIG. 2

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 01 20 4167

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	US 5 993 438 A (BILLE JOSEF F ET AL) 30 November 1999 (1999-11-30) * column 5, line 30 - line 56; claim 1; figure 4 *	1,7	A61F9/013
A	US 6 099 522 A (ORKISZEWSKI JERZY ET AL) 8 August 2000 (2000-08-08) * column 33, line 59 - column 34, line 15 *	1,7	
A	WO 94 09849 A (SWINGER CASIMIR A ;LAI SHUI T (US)) 11 May 1994 (1994-05-11) * page 23, paragraph 3 - page 25, paragraph 1; figure 3 *	1,7	

TECHNICAL FIELDS SEARCHED (Int.Cl.7)
A61F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	22 May 2002	Mayer, E

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 01 20 4167

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

22-05-2002

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5993438 A	30-11-1999	AU 8089298 A	04-03-1999
		CA 2242513 A1	21-02-1999
		EP 0903133 A2	24-03-1999
		JP 11192253 A	21-07-1999
		EP 0850089 A1	01-07-1998
		JP 11511051 T	28-09-1999
		WO 9706856 A1	27-02-1997
		AU 7761694 A	18-05-1995
		CA 2127029 A1	13-05-1995
		EP 0657151 A1	14-06-1995
		JP 7184951 A	25-07-1995
US 6099522 A	08-08-2000	US 5098426 A	24-03-1992
		AU 3781193 A	13-09-1993
		CA 2130999 A1	02-09-1993
		EP 0630205 A1	28-12-1994
		WO 9316631 A1	02-09-1993
		US 5865832 A	02-02-1999
		AU 651313 B2	21-07-1994
		AU 5161290 A	05-09-1990
		CA 2009368 A1	06-08-1990
		CN 1045028 A	05-09-1990
		EP 0426779 A1	15-05-1991
		JP 4503913 T	16-07-1992
		JP 3095079 B2	03-10-2000
		WO 9009141 A2	23-08-1990
WO 9409849 A	11-05-1994	AU 5540594 A	24-05-1994
		WO 9409849 A1	11-05-1994
		US 6325792 B1	04-12-2001

EPO FORM P0459